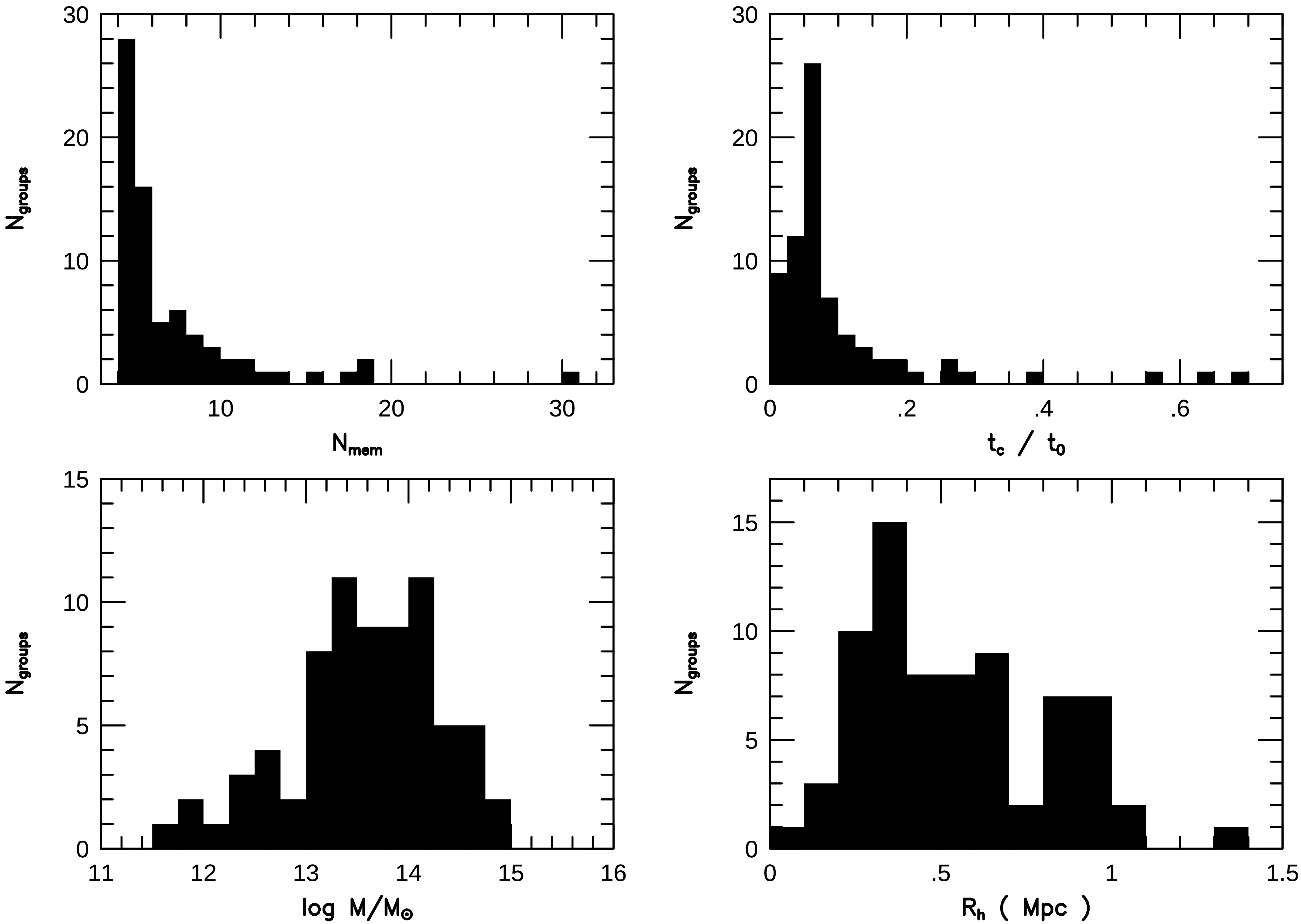

N_groups
N_mem
t_c / t_0
log M/M_⊙
R_h ( Mpc )

# STUDY OF A SLICE AT +9° TO +15° OF DECLINATION: I. THE NEUTRAL HYDROGEN CONTENT OF GALAXIES IN LOOSE GROUPS[1]

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[1]Research reported herein is based partly on observations obtained at Arecibo Observatory (Puerto Rico), Complejo Astronomico El Leoncito (Argentina), Laboratório Nacional de Astrofísica (Brazil) and European Southern Observatory (Chile).

## ABSTRACT

We examine the H I content of spiral galaxies in groups by using a catalog of loose groups of galaxies identified in a magnitude limited sample ($m_Z \leq 15.7$) spanning the range $8^h \leq \alpha \leq 18^h$ in right ascension and $+9^\circ \leq \delta \leq +15^\circ$ in declination. The redshift completeness of the galaxy sample is $\sim 95\%$. No significant effect of H I depletion is found, although there may be a hint that the earliest type spirals are slightly deficient.


*Subject headings:* Galaxies: H I content – galaxies: loose-groups

## 1. INTRODUCTION

Evidence that the internal properties of galaxies are in some ways determined by the large scale clustering has accumulated throughout the years. One of the first results suggesting this was presented by Davis & Geller (1976) who showed that early-type galaxies have different clustering properties than late-types. By studying a sample of rich clusters, Dressler (1980) was able to show that a well-defined relation exists over five orders of magnitude in density between the local density of galaxies and the relative proportions of different morphological types, the so called morphology-density relation. This was later shown to extend to lower density regions such as groups of galaxies by Postman & Geller (1984), and Maia & da Costa (1990). All these works show that the fraction of early-type galaxies increase with local density.

Several other galaxy properties have been claimed to be affected by the environment, such as the formation of cD galaxies, enhancement of star formation rate, presence of active galactic nuclei, bars in spiral galaxies, colors, and far infra-red emission, among others. In particular, it has been found that the neutral Hydrogen (H I) content of galaxies of a given morphological type depends on the environment (e.g., Haynes & Giovanelli 1986; Magri et al. 1988; Huchtmeier & Richter 1989; Scodeggio & Gavazzi 1993; and more recently Maia et al. 1994) in the sense that galaxies in denser regions, such as the core of clusters of galaxies, are H I deficient when compared to "field" galaxies (e.g., Haynes & Giovanelli 1986). This H I deficiency is usually attributed to the process of ram pressure sweeping. In a similar way Williams & Lynch (1991) detected a lower than average gas content for the spiral members in four poor clusters, while Williams & van Gorkom (1988); and Williams & Rood (1987) detected a similar effect when analyzing a few compact groups. Haynes (1981) found the presence of neutral hydrogen streams in 6 out of 15 groups of galaxies. In the paper of Giuricin, Mardirossian & Mezzetti (1985) they use galaxies in loose groups

identified by Geller & Huchra (1983) to examine the H I content. For a sample of 213 spiral and irregular galaxies they do not observe evidence of gas removal nor do they find a variation of the H I properties as a function of group compactness or even with the distance of the galaxies to the center of the groups. The fact that Geller & Huchra's (1983) groups are known to be plagued by interlopers may disguise some possible result in favor of H I deficiency, particularly if this effect is not conspicuous. Those results indicate that in clusters gas removal does occur; what happens in less dense structures is still an open question. There is observational evidence at several wavelengths for the presence of an intergalactic medium in loose groups, which could remove the gas from spiral galaxies (e.g., Dell'Antonio, Geller & Fabricant 1994; Henry et al. 1995; Mulchaey et al. 1996). Henry et al. (1995) claim that the x-ray luminosity and temperature functions may be considered as smooth extrapolations from that of rich clusters. There are also radio observations with the VLA in 20cm by Burns et al. (1987) who report the presence of tailed radio galaxies, and attribute this fact to the existence of an intragroup medium.

Besides the mechanism proposed above, tidal effects could be another possible process for gas removal which might be efficient in groups, since the velocity dispersions of those systems are low (typically $\approx 250$ km s$^{-1}$) and close encounters of galaxies will last considerable time, allowing the external parts of the galaxies to be removed. In fact, Davis et al. (1997) examining galaxies of loose groups using ROSAT, VLA and optical data concluded that both effects appear to be acting on the galaxies. They also suggest that the stripping of gas by the intragroup medium is made more efficient after a gravitational encounter.

Thus, we expect that the effect of gas removal may be present in some degree for density regimes such as those found in loose groups of galaxies. In this paper we generate a catalog of loose groups by means of objective criteria and the H I content for the

constituent galaxies is evaluated. We also examine the possible role of the mechanisms for gas removal driven either by hydrodynamic or by gravitational forces, in a typical loose group environment. The selection criteria of the sample of galaxies as well as the group definition are described in section 2, the H I content in group galaxies is analyzed in section 3. A brief conclusion is presented in section 4.

## 2. THE SAMPLE AND LOOSE GROUP DEFINITION

### 2.1. The Galaxy Sample

In this work we analyze a magnitude limited sample of galaxies taken from the *Catalog of Galaxies and Clusters of Galaxies* (Zwicky et al. 1961-68, hereafter CGCG), in the region of the sky defined by the intervals of declination +9° to +15° and right ascension of $8^h$ to $18^h$. A detailed description of the catalog, observations and data reduction will be given in a forthcoming paper, so only a brief description will be presented here. All the 2366 galaxies in this list up to $m_Z$=15.7 were visually inspected in overlays of the Palomar Observatory Sky Survey plates and had improved measurements of coordinates, major and minor diameters, as well as morphological types. Whenever possible, multiple systems had these parameters measured and magnitudes estimated for individual members. For those CGCG galaxies also listed in the *Uppsala General Catalog of Galaxies* (Nilson 1973, UGC) the morphological classification and diameter measurements were maintained as quoted in the UGC, unless we had a case of a split multiple system, when new parameters were calculated. Late-type galaxies (Sa and later) were selected to be observed with the 305 m Arecibo radiotelescope, while for the early-types as well as spirals which were not observed in 21 cm, we used the 2.15 m telescope of the Complejo Astronomico El Leoncito, San Juan, Argentina, the 1.6 m telescope of the Laboratório Nacional de Astrofísica, Itajubá, Brazil,

and the European Southern Observatory 1.52 m telescope[2], La Silla, Chile. At the present time, the redshift completeness of this sample is better than 95%. The incompleteness is partly caused by the observational procedure used in the 21cm survey. Typically the search for 21cm emission was carried out in the interval between 0 and $\approx 16000$ kms$^{-1}$ using bands of about 6000 kms$^{-1}$ . In the final period of the radio survey we carried out searches up to 25000 kms$^{-1}$ and several galaxies not detected previously, proved to be in that new search interval of velocities.

### 2.2. Determination of Loose Groups

The algorithm adopted for the construction of the catalog of groups of galaxies is basically the one described by Huchra & Geller (1982) with the improvements by Ramella et al. (1989) and by Maia, da Costa & Latham (1987) to minimize the number of interlopers. This percolation algorithm identifies groups of galaxies in a magnitude limited sample. A search for companions around galaxies is carried out taking into account projected separations satisfying

$$D_{12} = 2\sin(\theta_{12}/2)V/H_0 \leq D_L$$

and with line-of-sight velocity differences,

$$V_{12} = \mid V_1 - V_2 \mid \leq V_L$$

In the above expressions $V = (V_1 + V_2)/2$, $V_1$ and $V_2$ are the radial velocities of the

[2] The ESO 1.52 m telescope is operated under agreement between European Southern Observatory and Observatório Nacional/CNPq - Brazil.

galaxies, and $\theta_{12}$ their angular separation. The quantities $D_L$ and $V_L$ are search parameters scaled according to the expressions below in order to take into account the variation in the sampling of the galaxy luminosity function, $\phi(M)$, with distance

$$D_L = D_0 R \quad ; \quad V_L = V_0 R$$

where

$$R = \left[ \int_{-\infty}^{M_{12}} \Phi(M) dM \Big/ \int_{-\infty}^{M_{lim}} \Phi(M) dM \right]^{-1/3}$$

$$M_{lim} = m_{lim} - 25 - 5\log(V_f/H_0)$$

$$M_{12} = m_{lim} - 25 - 5\log[(V_1 + V_2)/2H_0]$$

$D_0$ is the selection parameter at a fixed fiducial radial velocity, $V_f$. $V_L$ is scaled in the same way as$D_L$. For the present work, the adopted values for $D_0$ and $V_0$ are 0.223 Mpc and 350 kms$^{-1}$ respectively; the apparent magnitude, $m_{lim} = 15.7$, and $H_o = 100$ kms$^{-1}$ Mpc$^{-1}$. The groups present a surrounding density contrast ($\delta\rho/\rho$) relative to the mean density of galaxies of 80 for a Schechter (1976) luminosity function calculated for the entire sample, parameterized by $\phi^* = 0.025$ galaxies mag$^{-1}$ Mpc$^{-3}$, $M^*_{B(0)} = -19.34$ and $\alpha = -1.38$.

Although the values we find are steeper them those found in some recent surveys (da Costa et al. 1994, Marzke et al. 1994), they are consistent with those of Ramella et al. (1989) and are very likely to be affected by the presence of the Virgo cluster. A total of 73 groups with 4 or more members and mean velocities $\leq$ 12,000 kms$^{-1}$ were identified. The global physical parameters as well as the presence of interlopers do not depend strongly on

redshift (see Ramella et al. 1989 for a more complete discussion). The physical parameters of the identified groups, are presented in Table 1 where we list the median and upper and lower quartile values for the velocity dispersion, $\sigma_v$; virial mass, $M$; crossing time, $t_c$; virial radius, $R_h$; and the mean projected separation, $R_p$. For a few parameters like number of member galaxies, $N_{mem}$, $t_c$, $log\ M$ and $R_p$ we display in Figure 1 histograms of the respective distributions. The results from both Table 1 and Figure 1 suggest that the identified groups have average properties similar to those identified by Ramella et al. (1989). The smaller crossing times and the short tail distribution of higher mass groups reflect the low contamination by interlopers.

## 3. THE NEUTRAL HYDROGEN CONTENT OF GALAXIES IN LOOSE GROUPS

A subsample called "Group" containing spiral galaxies with 21 cm information, members of the groups generated above is used to have the H I content of their galaxies estimated. We did not include in the analysis the group identified as part of the Virgo cluster because our intent is to examine the neutral Hydrogen content in structures with density regimes of groups. The galaxies which were not assigned to groups formed a subsample called "Isolated" that is used as a control sample. Isolated galaxies whose separation from the survey boundaries were smaller than the projected search radius appropriate for their radial velocity were removed from the "Isolated" sample. For both subsamples, only galaxies in the range of absolute magnitudes $-21 \leq M_Z \leq -17$, and radial velocities $\leq 12,000$ kms$^{-1}$ were considered in this analysis. The distribution of velocities for the galaxies in both samples is more or less the same, excluding the possible bias of a particular sample to be made up of only distant or nearby objects. Furthermore we have examined whether more massive galaxies could be more susceptible to loose their gas by

examining the distribution of the estimators with redshift for each morphological type and no such trend was detected.

Two estimators of the H I content are used. The first one, is the *Pseudo* H I surface density, $\Sigma_{HI}$, in $M_{\odot}pc^{-2}$, which is the total H I mass, $M_{HI}$, in solar units divided by the optical area of the galaxy, defined as

$$\Sigma_{HI} = M_{HI}/(\pi/4)D_B^2) \ ,$$

where

$$M_{HI} = 2.356 \times 10^5 \ d^2 F_c \ ,$$

and $D_B$ is the optical diameter in kpc, $d$ is the distance in Mpc, and $F_c$ is the 21cm line flux corrected for galaxy self-absorption, in Jy/kms$^{-1}$ as described by Haynes & Giovanelli (1984). The second estimator is the H I mass-to-light ratio, $M_{HI}/L_B$, in solar units, assuming a solar photographic absolute magnitude of +5.37. This estimator removes the dependence of the H I content on the blue galaxy luminosity, as well as reducing the scatter about the mean values than $M_{HI}$ alone (Giovanelli & Haynes 1988). By compiling a larger sample and using additional procedures, such as the one proposed by Solanes, Giovanelli & Haynes (1996) which takes into account a complete H I flux-limited data set, another methodology could be used. For the purpose of this paper we adopt the two estimators described above to perform the analysis of the H I content.

Table 2 presents the statistical results of the $\Sigma_{HI}$ distribution for both samples. Column (1) lists the morphological type, column (2) the number of galaxies of a given morphological type, $N$; column (3) the mean, $\bar{\Sigma}_{HI}$; column (4) the median, $(\Sigma_{HI})_{med}$; column (5) the standard deviation, $\sigma$; columns (6) and (7) the lower ($LQ$) and upper ($UQ$) quartiles of the distributions for "Isolated" galaxies. Columns (8) to (13), the same parameters as columns (2) to (7) for "Group" galaxies. The Kolmogorov-Smirnov test (KS), was applied to both subsamples for each morphological type, in order to determine whether they could all come

from the same parent population. Column (14) of Table 2 contains the probability, ($P_{KS}$), of this hypothesis occurring by chance.

In general, the statistical results presented in Table 2 show no significant dependence of $\Sigma_{HI}$ on the environment. Only the Sa and Sb galaxies in loose groups present some trend towards H I deficiency, while the intermediate sample of Sab galaxies presents no such effect. The results are summarized in figure 2, where we show the $(\Sigma_{HI})_{med}$ (dots) with respective $LQ$ and $UQ$ (bars) of the $\Sigma_{HI}$ distributions for each morphological type.

The statistics for the $M_{HI}/L_B$ estimator are presented in Table 3 and Figure 3. Here the evidence for the presence of H I depleted galaxies in groups is slightly stronger. Again, the earlier galaxies seem to be more affected by gas removal in the loose-group environment. The Sa-b galaxies with this estimator now show a tendency of being affected by the environment in contrast to the results obtained with $\Sigma_{HI}$. For the Sbs the evidence weakens significantly. The fact that the intrinsic scatter of the estimators for each morphological type is usually high, may produce these fluctuations on the results making it difficult to detect an unambiguously clear evidence towards H I deficiency, if present at all. Also, the large dispersion of the results may be partially caused by the fact that the sample is not H I flux limited.

A comparison between our results for $M_{HI}/L_B$ with others published in the literature is displayed in Figure 4, which shows the average values and standard deviations of $M_{HI}/L_B$ for galaxies of the Virgo cluster ("Cluster") obtained by Huchtmeier & Richter (1989), for "Group" and "Isolated" galaxies as defined in this work, and for the isolated sample (Iso2) of Haynes & Giovanelli (1984). The binning of Sa with Sa-b has been chosen to allow us to compare our results with those of the authors above. In Figure 4 we find that the control sample we have used presents an agreement with the Iso2. The smaller scatter in our "Isolated" sample is due to the restrictions in the absolute magnitude interval we have

applied. There is also a clear trend towards the H I deficiency for cluster galaxies but for "Group" galaxies, this effect is marginal.

An alternative mechanism for gas removal would be through tidal interactions. To examine this possibility, we have divided the "Group" sample according to the values of $\sigma_v$ of their respective groups. The $M_{HI}/L_B$ is examined for each subsample, which present values of $\sigma_v$ smaller and higher than the mean value for the entire group sample which is 231 kms$^{-1}$ . The results, displayed in Figure 5, do not present any systematic behavior with $\sigma_v$. In fact the Sa galaxies which we believe to show the strongest evidence of gas depletion, based on KS test, present the opposite behavior of what would be expected if tidal interactions would be the case. Therefore, this result tends to support the interpretation that early spirals have gas depletion by ram pressure stripping. However, it is intriguing that Scs when examined as a function of $\sigma_v$ show a hint that systems with low values of $\sigma_v$ are significantly more depleted than those with higher values. This seems to be in agreement with the results of Davis et al. (1997).

## 4. SUMMARY

We have examined the dependence of the H I content of spiral galaxies with local environment. For this purpose we identified loose-groups of galaxies by means of objective criteria. This procedure also allowed us to define a control sample of isolated galaxies. Two estimators were used to measure the H I content of galaxies: $\Sigma_{HI}$ and $M_{HI}/L_B$; both estimators show no clear tendency of spiral galaxies in loose-groups having a lower amount of neutral Hydrogen, although there may be a hint for the earliest spirals, but because of the small number of objects involved we cannot claim these results as being statistically significant. We have also evaluated whether the H I content of spiral galaxies shows any correlation with the group velocity dispersion. Our results are inconclusive. Ram

pressure may be a probable mechanism for producing the gas removal of galaxies in groups. However, the contribution to the gas stripping given by gravitational forces produced in close encounters cannot be discarded. By compiling a larger sample and using additional procedures, such as the one proposed by Solanes, Giovanelli & Haynes (1996), it might be possible to investigate the importance of hydrodynamical and gravitational forces to remove gas from galaxies of loose-groups.

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Fig. 1.— Histograms for different group parameters: number of member galaxies ($N_{mem}$), the crossing time ($t_c$) in units of Hubble time ($t_0$), The logarithm of the group mass ($logM$) in units of $M_{\odot}$, and the virial radius ($R_h$) in Mpc.

Fig. 2.— Medians, upper and lower quartiles of the $\Sigma_{HI}$ distributions discriminating galaxies between the different morphological types.

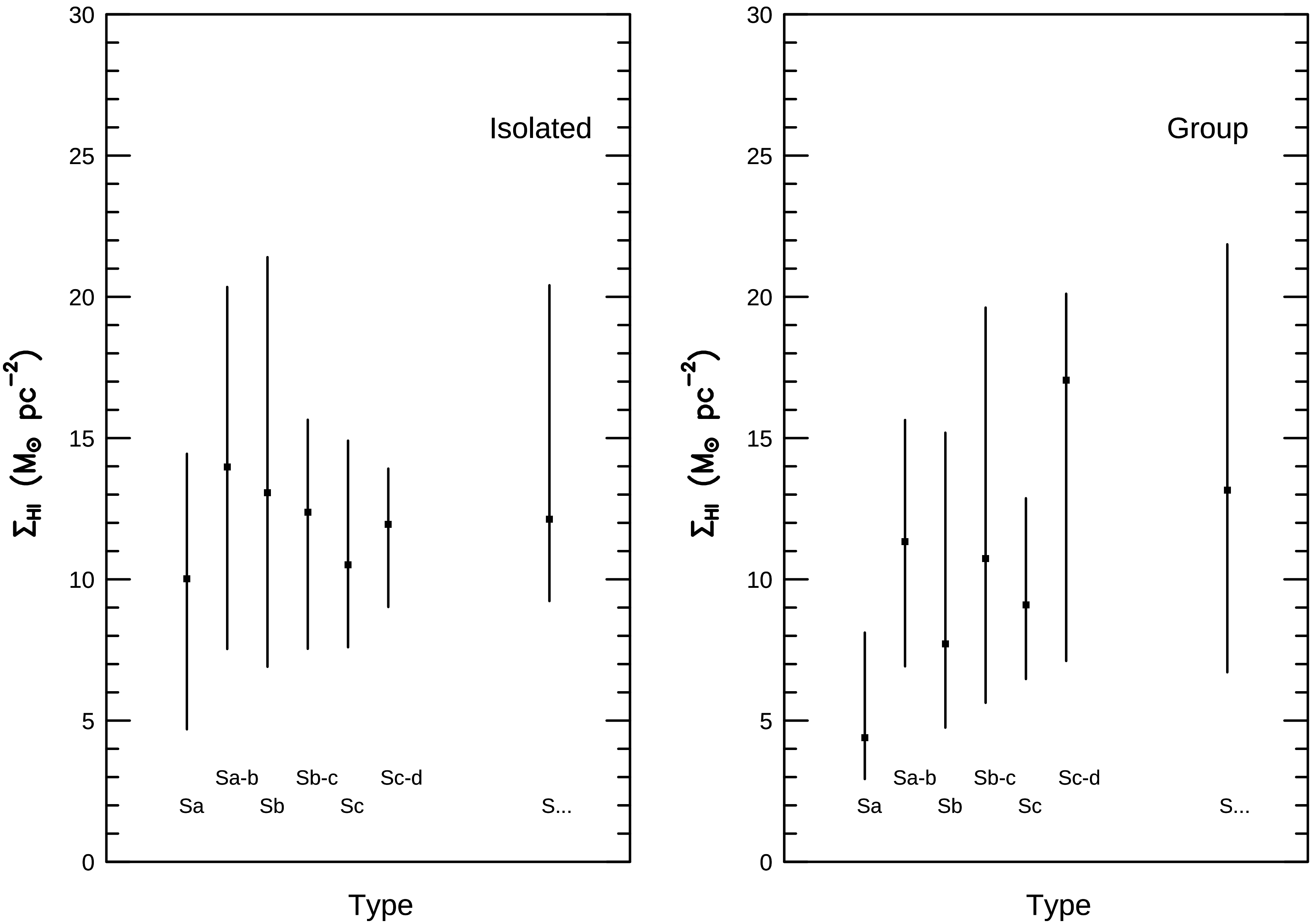
Fig. 3.— Medians, upper and lower quartiles of the $M_{HI}/L_B$ distributions discriminating galaxies between the different morphological types.

Fig. 4.— Mean and standard deviations for $M_{HI}/L_B$ distributions. The "Cluster" sample refers to Virgo cluster galaxies by Huchtmeier & Richter (1989); "Group" and "Isolated" as defined in this work, and "Iso2" for the isolated sample of Haynes & Giovanelli (1984).

Fig. 5.— Medians, upper and lower quartiles of the $M_{HI}/L_B$ distributions for subsamples of galaxies which belong to groups with values of $\sigma_v$ smaller and larger than the median value 231 kms$^{-1}$ of the entire sample of groups.

TABLE 1. Median values of group physical parameters

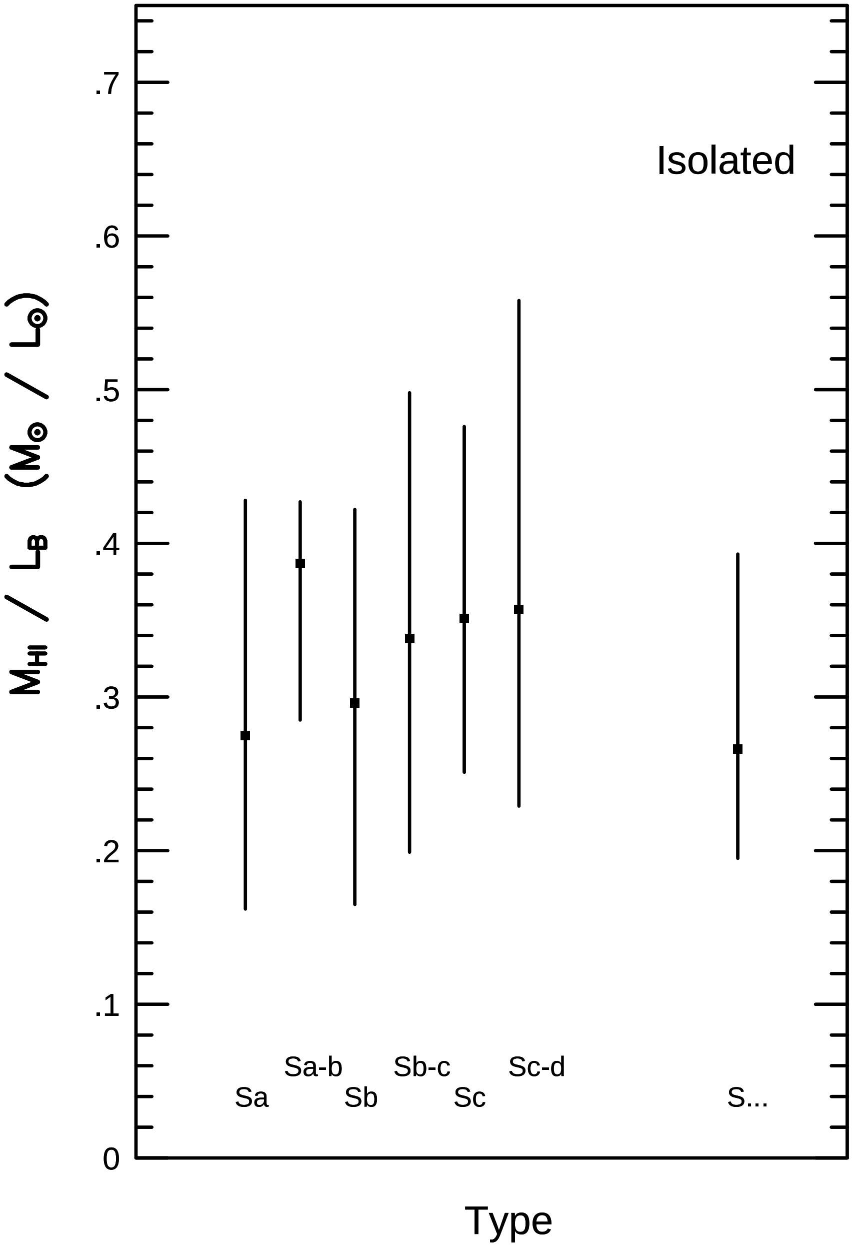
| Parameter | Median | Lower Quartile | Upper Quartile |
|---|---|---|---|
| $\sigma_v(kms^{-1})$ | 231 | 121 | 318 |
| $log(M/M_\odot)$ | 13.58 | 13.15 | 14.13 |
| $t_c/t_o$ | 0.060 | 0.040 | 0.095 |
| $R_h(Mpc)$ | 0.480 | 0.325 | 0.705 |
| $R_p(Mpc)$ | 0.690 | 0.435 | 1.160 |



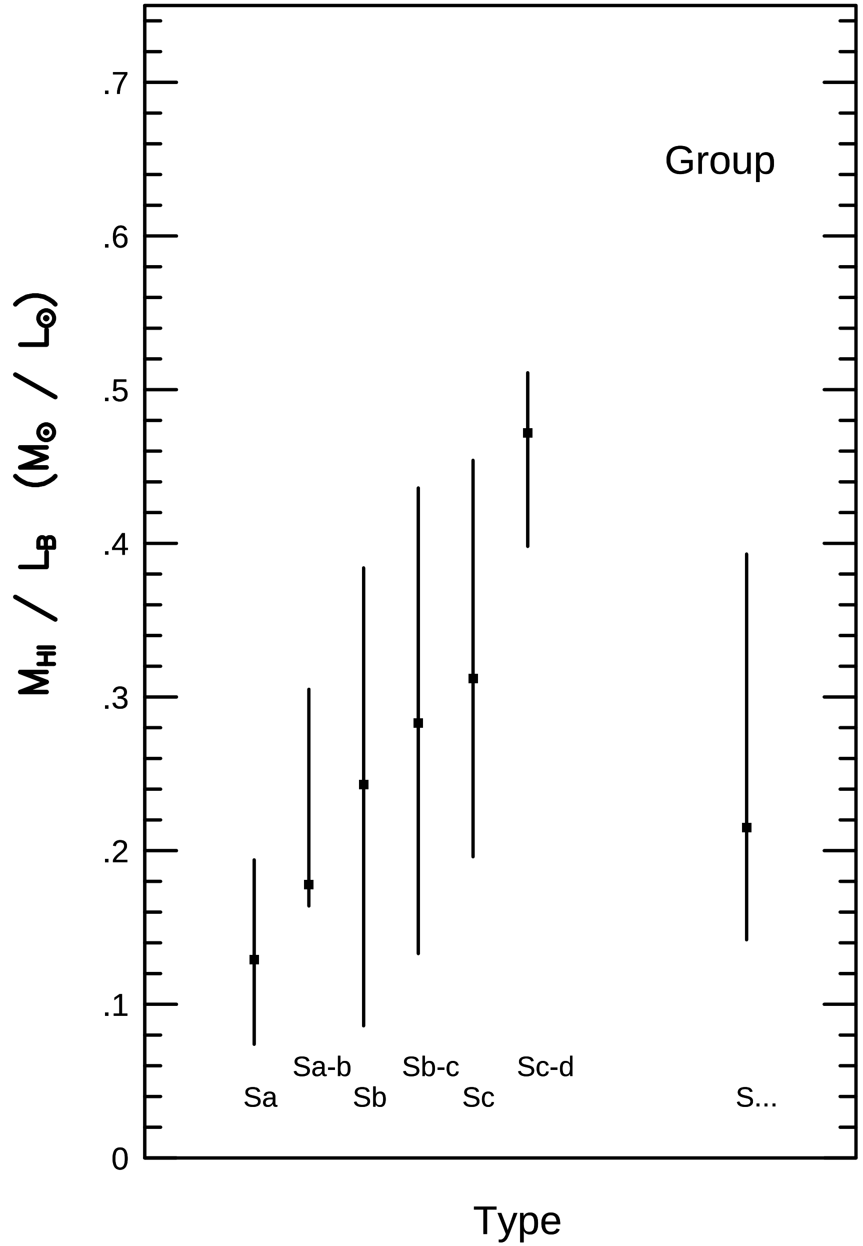
Isolated
Group
$\Sigma_{HI}$ ($M_\odot$ pc$^{-2}$)
Type
Sa
Sa-b
Sb
Sb-c
Sc
Sc-d
S...
0
5
10
15
20
25
30

TABLE 2. Statistics of $\Sigma_{HI}$ for galaxies of isolated and group samples

| | Isolated | | | | | | Group | | | | | | $P_{KS}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Type* | $N$ | $\overline{\Sigma_{HI}}$ | $(\Sigma_{HI})_{med}$ | $\sigma$ | $LQ$ | $UQ$ | $N$ | $\overline{\Sigma_{HI}}$ | $(\Sigma_{HI})_{med}$ | $\sigma$ | $LQ$ | $UQ$ | |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) |
| Sa | 11 | 11.05 | 10.02 | 5.61 | 4.69 | 14.44 | 19 | 15.89 | 4.39 | 35.47 | 2.93 | 8.11 | 0.042 |
| Sa-b | 13 | 17.71 | 13.98 | 13.72 | 7.53 | 20.35 | 12 | 13.82 | 11.33 | 9.48 | 6.92 | 15.64 | 0.942 |
| Sb | 53 | 16.03 | 13.07 | 11.51 | 6.90 | 21.40 | 46 | 14.94 | 7.72 | 30.75 | 4.75 | 15.19 | 0.033 |
| Sb-c | 36 | 12.68 | 12.37 | 6.51 | 7.54 | 15.65 | 20 | 14.22 | 10.73 | 10.33 | 5.63 | 19.62 | 0.615 |
| Sc | 77 | 12.89 | 10.51 | 8.05 | 7.59 | 14.91 | 52 | 10.88 | 9.09 | 6.89 | 6.47 | 12.87 | 0.292 |
| Sc-d | 13 | 12.32 | 11.94 | 3.98 | 9.02 | 13.92 | 4 | 16.48 | 17.05 | 7.64 | 7.11 | 20.11 | 0.587 |
| S... | 67 | 18.34 | 12.13 | 14.61 | 9.23 | 20.41 | 57 | 17.83 | 13.16 | 15.23 | 6.71 | 21.86 | 0.524 |



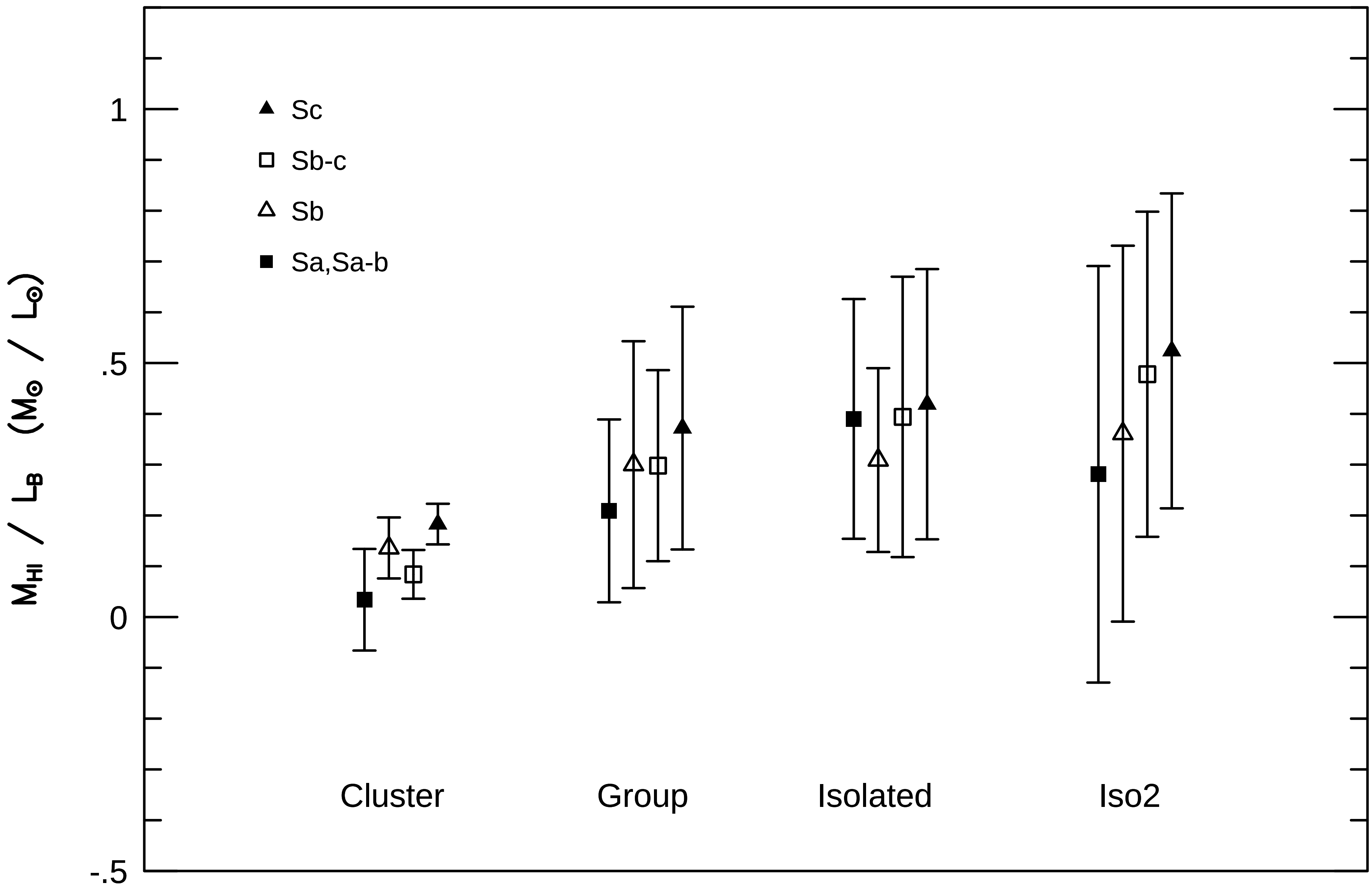
Isolated
$M_{HI}$ / $L_B$ ($M_\odot$ / $L_\odot$)
.7
.6
.5
.4
.3
.2
.1
0
Sa
Sa-b
Sb
Sb-c
Sc
Sc-d
S...
Type

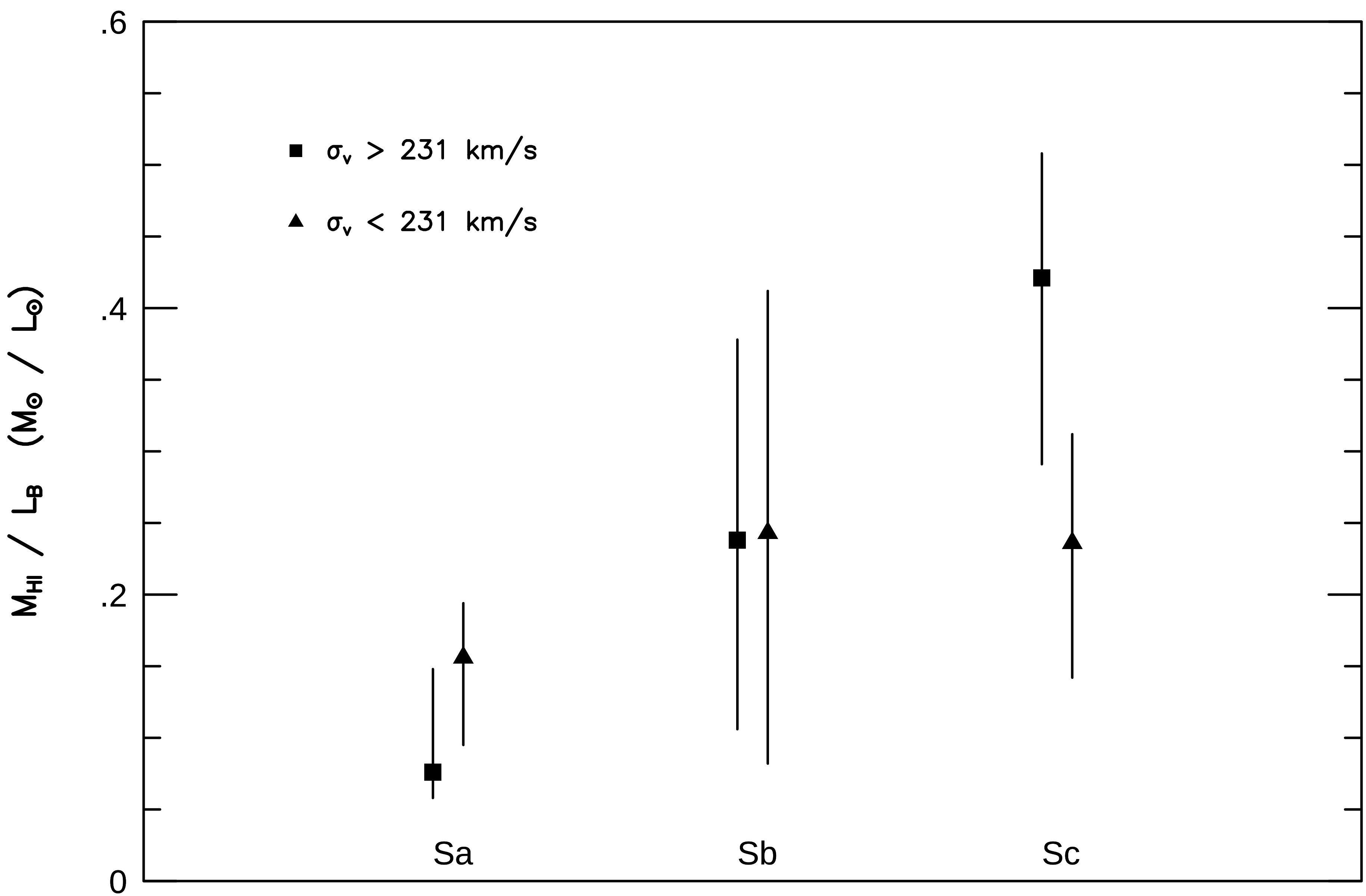
Group
$M_{HI}$ / $L_B$ ($M_\odot$ / $L_\odot$)
.7
.6
.5
.4
.3
.2
.1
0
Sa
Sa-b
Sb
Sb-c
Sc
Sc-d
S...
Type

Table 3. Statistics of $M_{HI}/L_B$ for galaxies of isolated and group samples

| | Isolated | | | | | | Group | | | | | | $P_{KS}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Type* | $N$ | $\overline{M_{HI}/L_B}$ | $\left(\frac{M_{HI}}{L_B}\right)_{med}$ | $\sigma$ | $LQ$ | $UQ$ | $N$ | $\overline{M_{HI}/L_B}$ | $\left(\frac{M_{HI}}{L_B}\right)_{med}$ | $\sigma$ | $LQ$ | $UQ$ | |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) |
| Sa | 11 | 0.337 | 0.275 | 0.212 | 0.162 | 0.428 | 19 | 0.196 | 0.129 | 0.213 | 0.074 | 0.194 | 0.011 |
| Sa-b | 13 | 0.434 | 0.387 | 0.255 | 0.285 | 0.427 | 12 | 0.230 | 0.178 | 0.114 | 0.164 | 0.305 | 0.026 |
| Sb | 53 | 0.309 | 0.296 | 0.181 | 0.165 | 0.422 | 46 | 0.300 | 0.243 | 0.243 | 0.086 | 0.384 | 0.339 |
| Sb-c | 36 | 0.394 | 0.338 | 0.276 | 0.199 | 0.498 | 20 | 0.298 | 0.283 | 0.188 | 0.133 | 0.436 | 0.582 |
| Sc | 77 | 0.419 | 0.351 | 0.266 | 0.251 | 0.476 | 52 | 0.372 | 0.312 | 0.239 | 0.196 | 0.454 | 0.360 |
| Sc-d | 13 | 0.452 | 0.357 | 0.285 | 0.229 | 0.558 | 4 | 0.532 | 0.472 | 0.176 | 0.398 | 0.511 | 0.532 |
| S... | 67 | 0.323 | 0.266 | 0.191 | 0.195 | 0.393 | 57 | 0.287 | 0.215 | 0.205 | 0.142 | 0.393 | 0.076 |



Sc
Sb-c
Sb
Sa,Sa-b
1
.5
0
-.5
$M_{HI}$ / $L_B$ ($M_\odot$ / $L_\odot$)
Cluster
Group
Isolated
Iso2



$\sigma_v > 231$ km/s
$\sigma_v < 231$ km/s
$M_{HI} / L_B$ $(M_\odot / L_\odot)$
.6
.4
.2
0
Sa
Sb
Sc